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A SOIL PRESSURE GAUGE FOR LABORATORY MODEL RESEARCH

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A SOIL PRESSURE GAUGE FOR FOR LABORATORY MODEL RESEARCH

Peter W. Rowe,[1]

SYNOPSIS

A soil pressure gauge 1.50 in. diameter is described, suitable for pressure ranges 0.01 to 0.50 lb. per sq. in. The gauge is free of error due to soil arching, and zero wander, and is particularly suitable for investigating the distribution of soil pressures on laboratory models of structures.

INTRODUCTION

A simple inexpensive soil pressure gauge of a size sufficiently small to allow close spacing along laboratory models of structures has many applications to the teaching and research work in soil mechanics.[2] Such a gauge was developed for a recent investigation of sheet-pile walls.[3] The gauge was designed initially for use in the laboratory at a soil boundary, but the principle may be extended to field gauges and gauges placed within the soil mass.

The most extensive research into the factors affecting the design of soil pressure gauges is that by the U. S. Waterways Experimental Station,[4] which deals with gauges for use in the field. The W.E.S. gauge uses an electrical strain gauge to measure the radial strain in a diaphragm, deflected relative to the cell perimeter by soil pressure. The gauges were designed for pressures ranging from 10-100 lb./in.^{2}, and varied from 3.5 - 24 in. in diameter. The principle findings of all their tests on various sizes and types of gauge may be summarized as follows:

(1) A gauge placed at a soil boundary should not protrude into the soil by a distance exceeding 1/30th the gauge diameter.
(2) The central deflexion of the diaphragm of a boundary gauge should not exceed 1/1000th the diameter.
(3) A gauge placed within the soil should have a diameter: thickness ratio exceeding 5.
(4) The central deflexion of the diaphragm of a gauge placed within the soil should not exceed 1/2000th the diameter.

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1. Lecturer in Civ. Eng., The University, Manchester, England.
2. "Field Study of a Sheet-Pile Bulkhead," C. Martin Duke, Proc. Separate No: 155 (see p. 25).
3. "Anchored Sheet Pile Walls," P. W. Rowe. Proc. Inst. Civ. Eng., London, Vol. I, Part I, 1952.
4. Soil Pressure Cell Investigation, U. S. Waterways Exp. Station Tech. Memorandum No: 210-1.

Note: Small super numerals in the following text refer to the above references.

The report also contains a short review of other types of pressure cell including one by the California State Highway Department, in which the deflexion of a steel diaphragm was measured using the principle of magnetic induction.

The gauge to be described was also designed on the induction principle, but greater sensitivity has been obtained by the use of two inductive circuits.

Principle and Design

The principle of the inductive circuit is shown in Fig. 1. It consists of two iron core inductive circuits carrying a central armature. The primary windings carry currents in opposite directions, the secondary windings being connected in series. When the armature is central, equal and opposite electromotive forces are induced in the secondary windings so that no current flows round the secondary circuit. With armature displacement an increase occurs in the induced secondary e.m.f. of one circuit, whereas a decrease occurs in the other. Since the primary circuits are reversed a total current flows in the secondary circuit equivalent to twice the induced e.m.f. of one coil. This method provides both an automatic balance at zero, and doubles the magnification, compared with the use of a single induction circuit. The secondary current may be amplified and read direct on a milliammeter, or rectified and read on a galvonometer. Since no current flows with the armature central, the secondary magnification and hence sensitivity of the gauge is limited only by the extent to which the flux paths of the two circuits may be matched.

In order to determine the optimum conditions of primary current, air gap and diaphragm thickness for various pressure ranges, the experimental rig shown in Fig. 2 was constructed. The total air gap between the circuits was controlled by a fine threaded screw A provided with a capstan head to facilitate adjustment. The armature position was controlled independently by screw B, which moved the water pressure chamber and diaphragm to which the armature was attached. The armature movement was calibrated by mounting a dial gauge reading to 1×10^{-4}, on the armature spindle axis. Tests were made for pressure ranges up to 4 lb./in.^{2} using diaphragms from 0.003" to 0.010" thick, air gaps varying from 0.004" to 0.030", and primary currents between 0.5 and 1.25 amps. These tests showed that using an air gap of 0.005", and a primary current of 0.60 amps, the smallest division on the milliammeter corresponded to a diaphragm movement of 1×10^{-6} inch. These movements were well within the requirements of the W.E.S. results which allow a maximum central deflexion of 1.25×10^{-3} inch on the diaphragm used.

The iron cores to the inductive circuits had been made in soft magnetic iron in the first place. These were replaced by cores of mild steel with no loss in efficiency, since the flux density carried was well below saturation limit. The use of mild steel throughout facilitates the production of the gauges.

As a result of these tests the gauge shown in Fig. 3 was designed. The chief features are

(1) The flux paths of each circuit must balance. Where a join occurs between components, as at A, a path should be provided across a plane surface in uniform contact rather than across a screw thread. The number of windings in the primary and secondary coils respectively must be identical in each circuit.

(2) The gauge is self compensating with respect to temperature change except for the negligible influence of the brass flux insulator between the diaphragm and the armature.
(3) The gauge may be set to read zero before test from outside the model by rotating the diaphragm and thus controlling the armature air gaps.
(4) The armature faces should be parallel to themselves and to the faces of the cores of each circuit.
(5) There are no pivoted or sliding parts requiring special fit and the components may be produced in quantity at reasonable cost.

Performance

The gauge performance under soil pressure was determined in the following manner. The gauge was screwed flush with a horizontal steel plate 24 inches square and $\frac{3}{8}$ in. thick. This was supported clear of the ground by steel beams 3 inches wide, 1 inch deep, at 2 inch intervals spanning 15 inches. The maximum deflexion of the plate when loaded with 12 inches of sand was of the order of 1×10^{-4} inch. The gauge was first calibrated using water pressure. Tests with soil were made placing a 24 inch square bottomless box on the plate such that the gauge was at the centre, and the soil was placed loosely in 1 inch layers.

The following soils were tested:

(a) A uniformly graded fine river sand having the bulk of the particles at about 0.008 inch mesh.
(b) Leighton Buzzard sand having a uniform size at 0.03 inch, and
(c) Lead shot at 0.06 inch dia.

Tests were also made in which particles finer than 0.008 inch mesh were sieved from the river sand and placed over the gauge first, the procedure being repeated for samples of sand at higher uniform sizes. The gauge was also calibrated in a horizontal position using water.

The results of these tests are shown in Fig. 4, and may be summarized as follows:

(1) A uniformly graded sand gives identical fluid pressure on the diaphragm up to a maximum deflexion of 0.001 inch. (1/1250 x diaphragm diameter).
(2) Lead shot of uniform size of 1/20th the diaphragm diameter commences to arch over the gauge at a central deflexion equal to approximately 2×10^{-4} inch. (1/6000 x diaphragm diameter).
(3) A uniform material up to 0.03 inch mesh gives a uniform calibration which differs slightly from that of a fluid of a naturally graded material.

The calibration curve at full amplification departs from the straight line towards the higher currents. This is a characteristic of the output circuit of the amplifier.

These results show that laboratory "active" soil pressures ranging from 0.01 to 0.5 lb./in.^{2} may be accurately measured using diaphragm displacements up to 6×10^{-4} inch, provided medium to fine uniformly graded soils are used. Higher "passive" pressure ranges are obtained by increasing the diaphragm thickness. Only a low sensitivity is necessary therefore, and this allows more tolerance in the construction of the gauge, and simplifies its use. Smaller gauges of $\frac{1}{2}$ inch diameter diaphragm could well be made, using a rectifier and galvanometer to detect the currents.

Repeated tests over several months have shown that the gauge retains its initial calibration. Measurements taken with the water pressure on increase and decrease of pressure, show that there is virtually no diaphragm hysteresis. Wander of the zero occurs to the order of 2%.

In addition to the use of this gauge in laboratory research work, the application of the principle to field gauges appears to be promising. The currents measured on the laboratory gauge were large compared with those detected in strain gauge circuits, and no particular care is necessary over connections or switches. A field gauge of 24 in. diameter would operate with coarser soils and allow diaphragm deflexions 19 times those used above before soil arching occurred, with correspondingly larger current changes to measure.

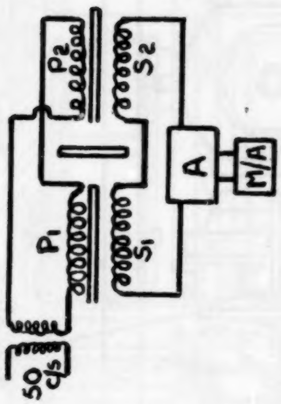


Fig 1 Circuit Wiring

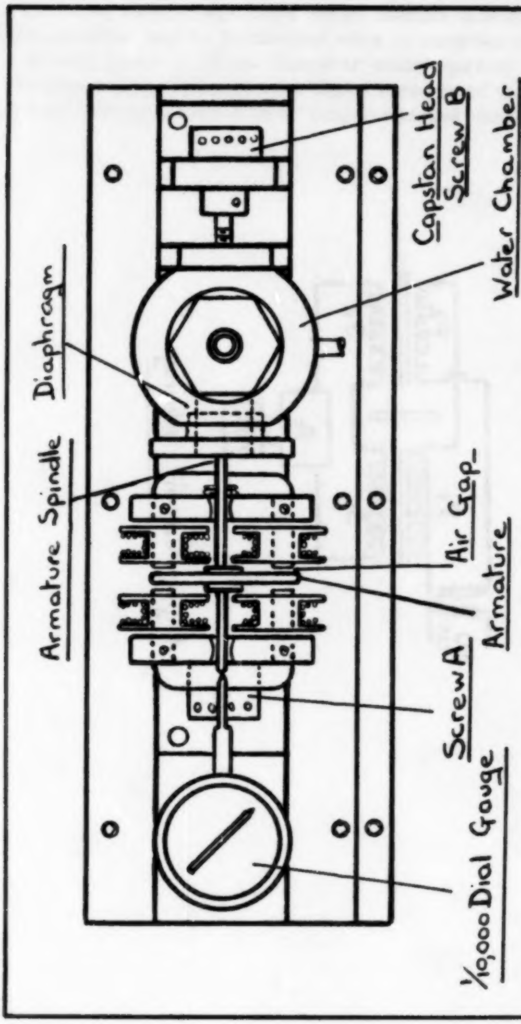
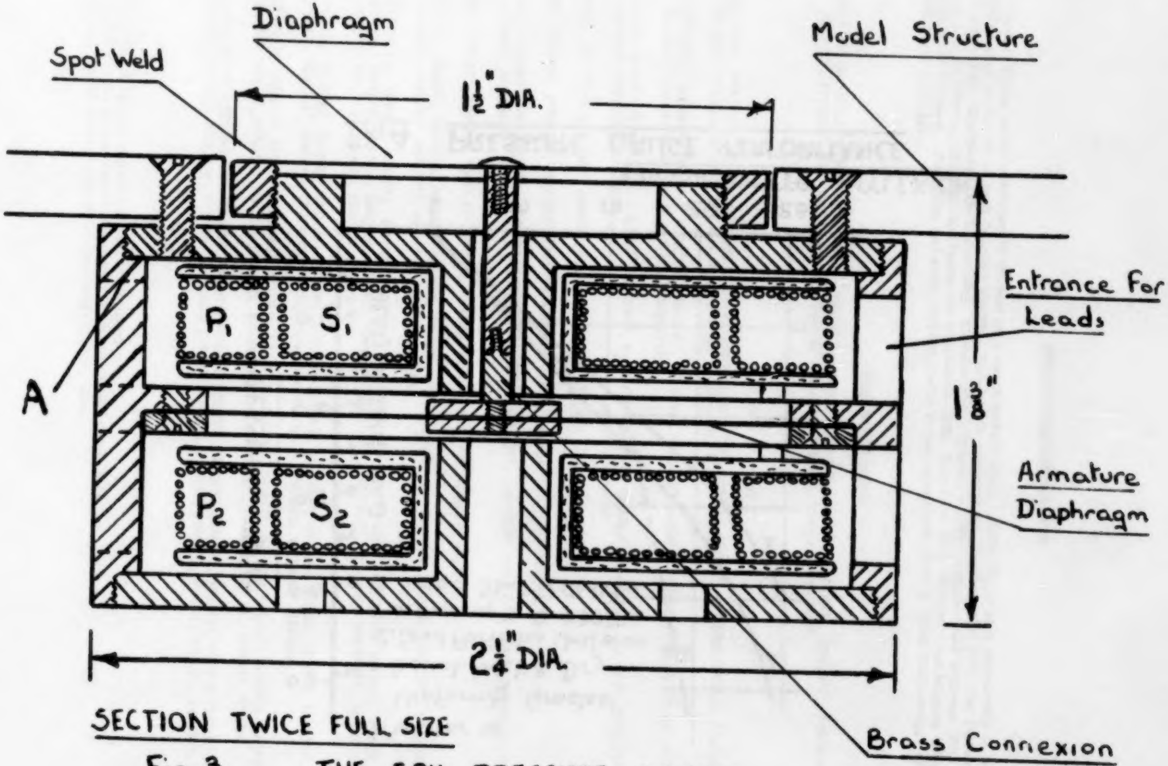


Fig 2 PRESSURE GAUGE TEST APPARATUS 1/2 Full Size Plan



SECTION TWICE FULL SIZE

Fig. 3 THE SOIL PRESSURE GAUGE

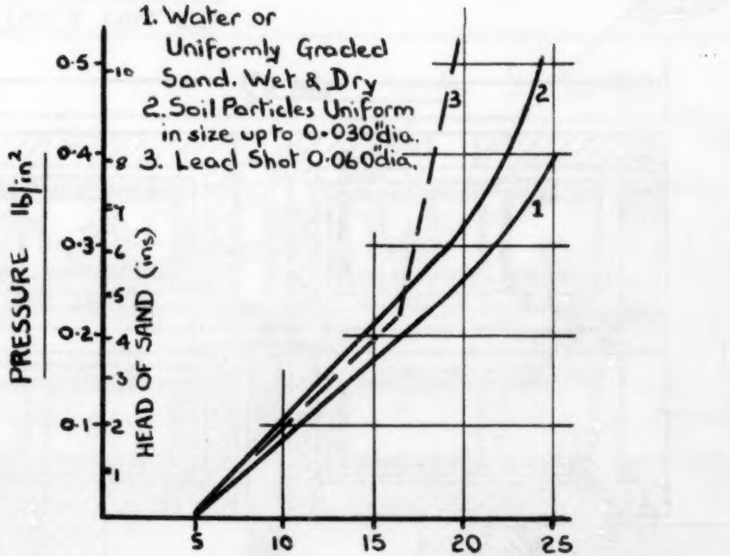


Fig 4 PRESSURE GAUGE PERFORMANCE

PROCEEDINGS-SEPARATES

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VOLUME 79 (1953)

DECEMBER: 359(AT), 360(SM), 361(HY), 362(HY), 363(SM), 364(HY), 365(HY), 366(HY), 367(SU)[c], 368(WW)[c], 369(IR), 370(AT)[c], 371(SM)[c], 372(CO)[c], 373(ST)[c], 374(EM)[c], 375(EM), 376(EM), 377(SA)[c], 378(PO)[c].

VOLUME 80 (1954)

JANUARY: 379(SM)[c], 380(HY), 381(HY), 382(HY), 383(HY), 384(HY)[c], 385(SM), 386(SM), 387(EM), 388(SA), 389(SU)[c], 390(HY), 391(IR)[c], 392(SA), 393(SU), 394(AT), 395(SA)[c], 396(EM)[c], 397(ST)[c].

FEBRUARY: 398(IR)[d], 399(SA)[d], 400(CO)[d], 401(SM)[c], 402(AT)[d], 403(AT)[d], 404(IR)[d], 405(PO)[d], 406(AT)[d], 407(SU)[d], 408(SU)[d], 409(WW)[d], 410(AT)[d], 411(SA)[d], 412(PO)[d], 413(HY)[d].

MARCH: 414(WW)[d], 415(SU)[d], 416(SM)[d], 417(SM)[d], 418(AT)[d], 419(SA)[d], 420(SA)[d], 421(AT)[d], 422(SA)[d], 423(CP)[d], 424(AT)[d], 425(SM)[d], 426(IR)[d], 427(WW)[d].

APRIL: 428(HY)[c], 429(EM)[c], 430(ST), 431(HY), 432(HY), 433(HY), 434(ST).

MAY: 435(SM), 436(CP)[c], 437(HY)[c], 438(HY), 439(HY), 440(ST), 441(ST), 442(SA), 443(SA).

JUNE: 444(SM)[e], 445(SM)[e], 446(ST)[e], 447(ST)[e], 448(ST)[e], 449(ST)[e], 450(ST)[e], 451(ST)[e], 452(SA)[e], 453(SA)[e], 454(SA)[e], 455(SA)[e], 456(SM)[e].

JULY: 457(AT), 458(AT), 459(AT)[c], 460(IR), 461(IR), 462(IR), 463(IR)[c], 464(PO), 465(PO)[c].

AUGUST: 466(HY), 467(HY), 468(ST), 469(ST), 470(ST), 471(SA), 472(SA), 473(SA), 474(SA), 475(SM), 476(SM), 477(SM), 478(SM)[c], 479(HY)[c], 480(ST)[c], 481(SA)[c], 482(HY), 483(HY).

SEPTEMBER: 484(ST), 485(ST), 486(ST), 487(CP)[c], 488(ST)[c], 489(HY), 490(HY), 491(HY)[c], 492(SA), 493(SA), 494(SA), 495(SA), 496(SA), 497(SA), 498(SA), 499(HW), 500(HW), 501(HW)[c], 502(WW), 503(WW), 504(WW)[c], 505(CO), 506(CO)[c], 507(CP), 508(CP), 509(CP), 510(CP), 511(CP).

OCTOBER: 512(SM), 513(SM), 514(SM), 515(SM), 516(SM), 517(PO), 518(SM)[c], 519(IR), 520(IR), 521(IR), 522(IR)[c], 523(AT)[c], 524(SU), 525(SU)[c], 526(EM), 527(EM), 528(EM), 529(EM), 530(EM)[c], 531(EM), 532(EM)[c], 533(PO).

NOVEMBER: 534(HY), 535(HY), 536(HY), 537(HY), 538(HY)[c], 539(ST), 540(ST), 541(ST), 542(ST), 543(ST), 544(ST), 545(SA), 546(SA), 547(SA), 548(SM), 549(SM), 550(SM), 551(SM), 552(SA), 553(SM)[c], 554(SA), 555(SA), 556(SA), 557(SA).

DECEMBER: 558(ST), 559(ST), 560(ST), 561(ST), 562(ST), 563(ST)[c], 564(HY), 565(HY), 566(HY), 567(HY), 568(HY)[c], 569(SM), 570(SM), 571(SM), 572(SM)[c], 573(SM)[c], 574(SU), 575(SU), 576(SU), 577(SU), 578(HY), 579(ST), 580(SU), 581(SU), 582(Index).

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c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.